MSSM Higgs Bosons at the Tevatron

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P. D., Tao Liu, and Carlos E.M. Wagner, Phys. Rev. D 80, 035025 (2009)

Introduction

- The Tevatron reach for the Standard Model Higgs is getting stronger.
- Current exclusion at 95% C.L for
  $160\ \mathrm{GeV} < m_h < 170\ \mathrm{GeV}$
- Current data set is $\approx 7\ \mathrm{fb}^{-1}/\mathrm{experiment}$
- May run for two more years, gaining
  $\approx 2\ \mathrm{fb}^{-1}/\mathrm{experiment}/\mathrm{year}$
- May be able to improve signal efficiencies in some channels.

Goal

What efficiency and luminosity improvements are necessary to constrain large regions of the MSSM Higgs parameter space?

Constraints on m_h in the SM

- Tevatron searches produce constraints on the signal relative to the signal predicted by the SM:

$$\frac{\sigma \times \mathrm{Br}}{\sigma_{SM} \times \mathrm{Br}_{SM}} \leq R^{95}_{SM}$$

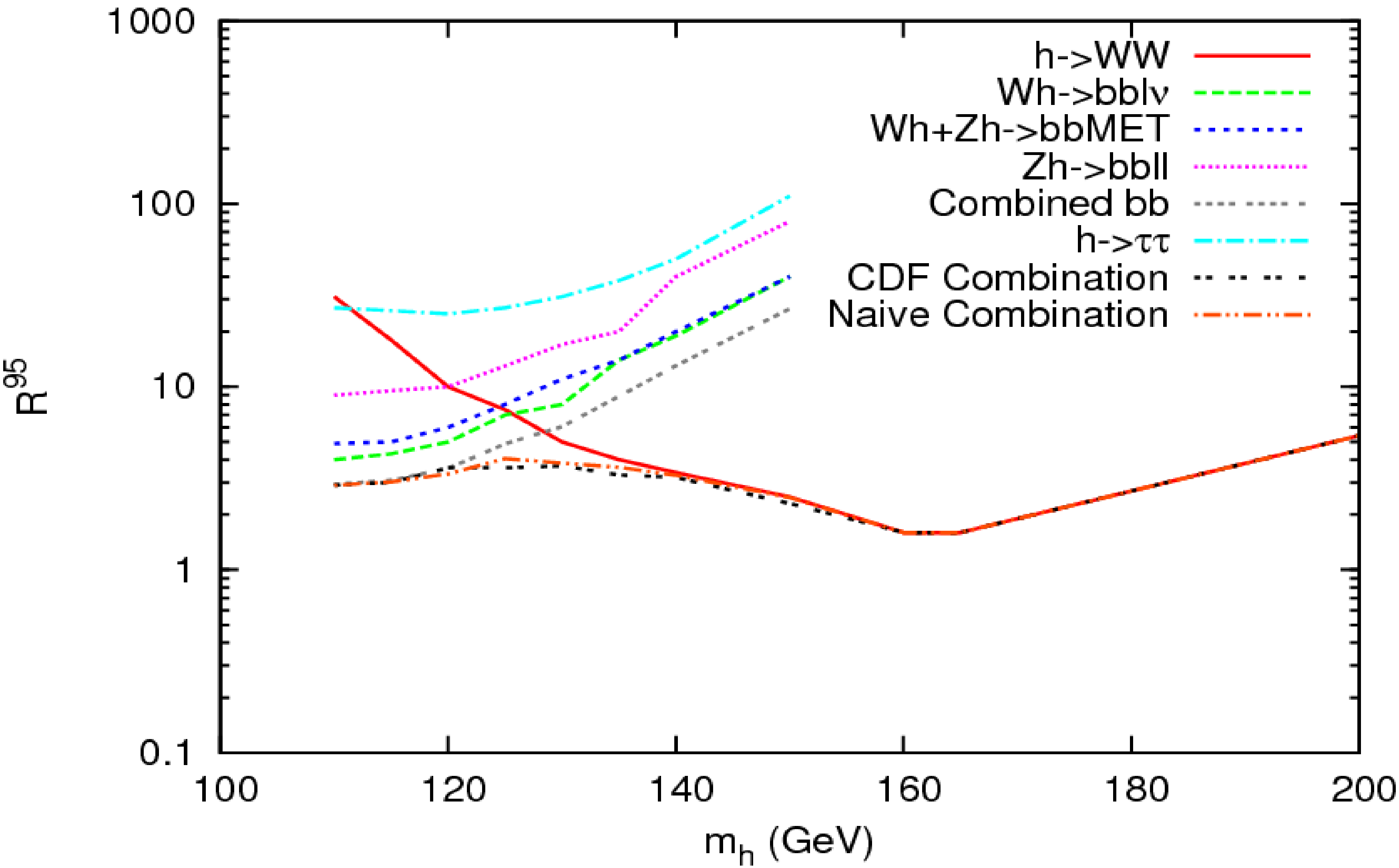
- Can compute naïve expected limits in each channel *i* at 95% C.L. (statistical errors, no signal, b>>1):

$$R^{95}_{SM,i} = 2 \times \sqrt{b_i}/s_i$$

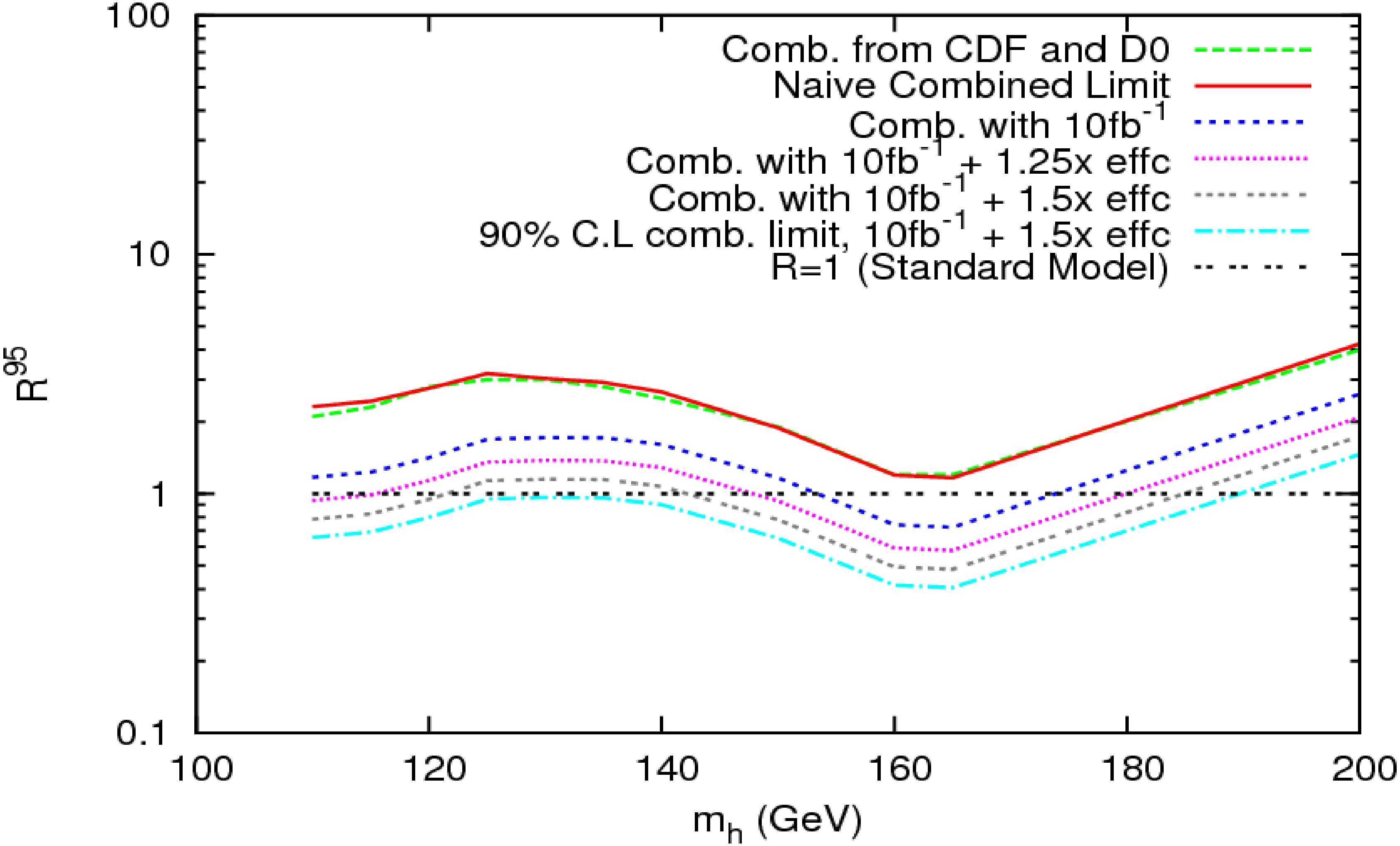
- → Combined expected limit:

$$\frac{1}{(R^{95}_{SM})^2} = \sum_i \frac{1}{(R^{95}_{SM,i})^2}$$

Naïve Combined Limit vs CDF



Naïve Combined Limit vs Limit from CDF + D0



- R^{95}_{SM} scales with luminosity as $L^{-1/2}$ and signal efficiency as e^{-1}

Translating Limits into the MSSM

- Rescale limits from individual channels

$$R^{95}_{MSSM,i} = R^{95}_{SM,i} \times \frac{\sigma_{SM,i} \times \mathrm{Br}_{SM,i}}{\sigma_{MSSM,i} \times \mathrm{Br}_{MSSM,i}}$$

- Allow each channel to go through any MSSM Higgs state:

$$gg \to (h, H) \to WW;\, b\bar{b} \to (h, H, A) \to \tau^+\tau^-$$

- Recombine. Limit is a function of MSSM parameters.
- Differs from SM: rescaled couplings

$$g_{hdd} = -(m_d/v)\frac{\sin\alpha}{\cos\beta} \quad g_{huu} = (m_u/v)\frac{\cos\alpha}{\sin\beta}$$

$$g_{hVV} \propto \sin(\beta - \alpha)$$

SM-like vs. Nonstandard Higgs

- Typically one CP-even Higgs is SM-like in its couplings to gauge bosons, while the other has negligible gauge couplings and tan β-enhanced down-type fermion couplings
- Decoupling limit: m_A large, h SM-like. Antidecoupling limit: m_A small, H SM-like.
- $m_{nonstandard} \simeq m_A$
- Can search for SM-like Higgs with associated production or *WW* decays, but nonstandard searches require gluon/bottom quark fusion and down-type fermionic decays (also works for *A*)
- Classification fails for $m_A \simeq m_{\phi_{SM}}^{max} \simeq 125\ \mathrm{GeV}$ and moderate tan β, where both *h* and *H* have reduced but sizeable gauge couplings. Here $m_A \simeq m_h \simeq m_H$ and all have enhanced couplings to down-type fermions

MSSM Benchmark Scenarios

- At tree level, m_A and $\tan\beta$ determine the Higgs spectrum and couplings to the SM.
- At loop level, more parameters enter $A_t,\ \mu,\ M_S \ldots$
- Choose sets of benchmark values representative of different effects of the radiative corrections
- Scan over $(m_A, \tan\beta)$ plane, compute combined R^{95}_{MSSM}
- Plot 95% C.L. exclusions for various increases in luminosity and signal efficiency
- Initially, keep separate combined limits from SM-like Higgs search channels and MSSM direct searches to see complementarity.

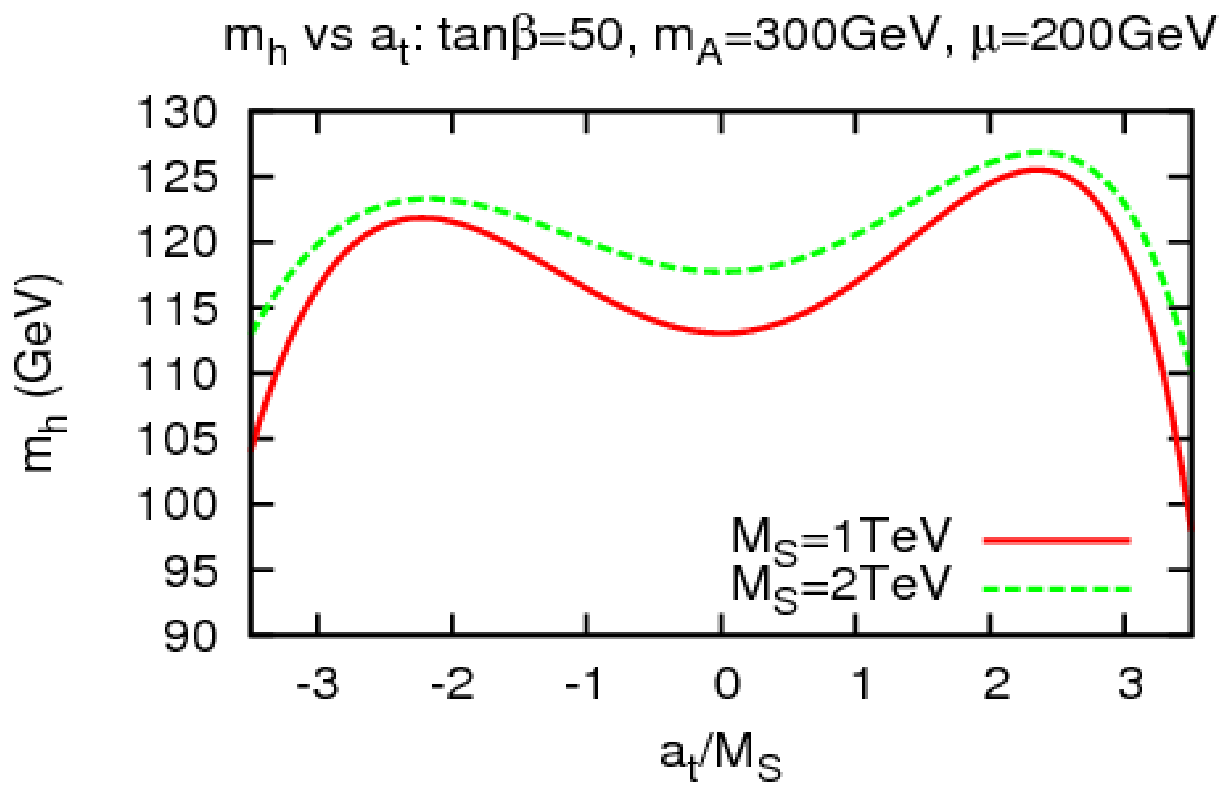
Minimal Mixing Scenario

- Off-diagonal component $a_t \equiv A_t - \mu / \tan\beta$ of $\tilde{t}$ mass matrix chosen small so that m_h is minimized,

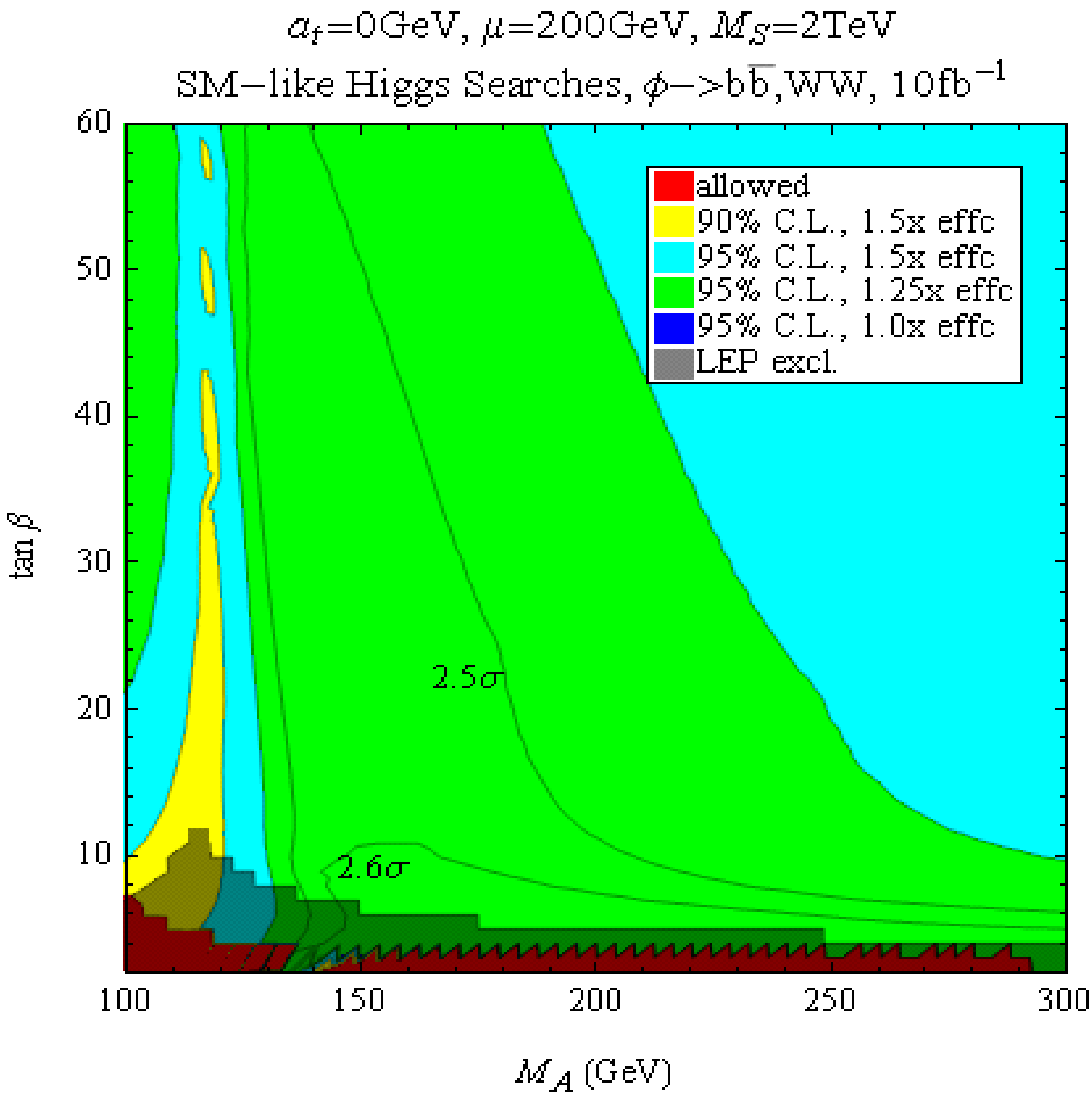
  $m_h \sim 110 - 118 \text{ GeV}$

- Soft mass scale raised to (partially) avoid LEP bounds
- Lighter Higgs → stronger constraints

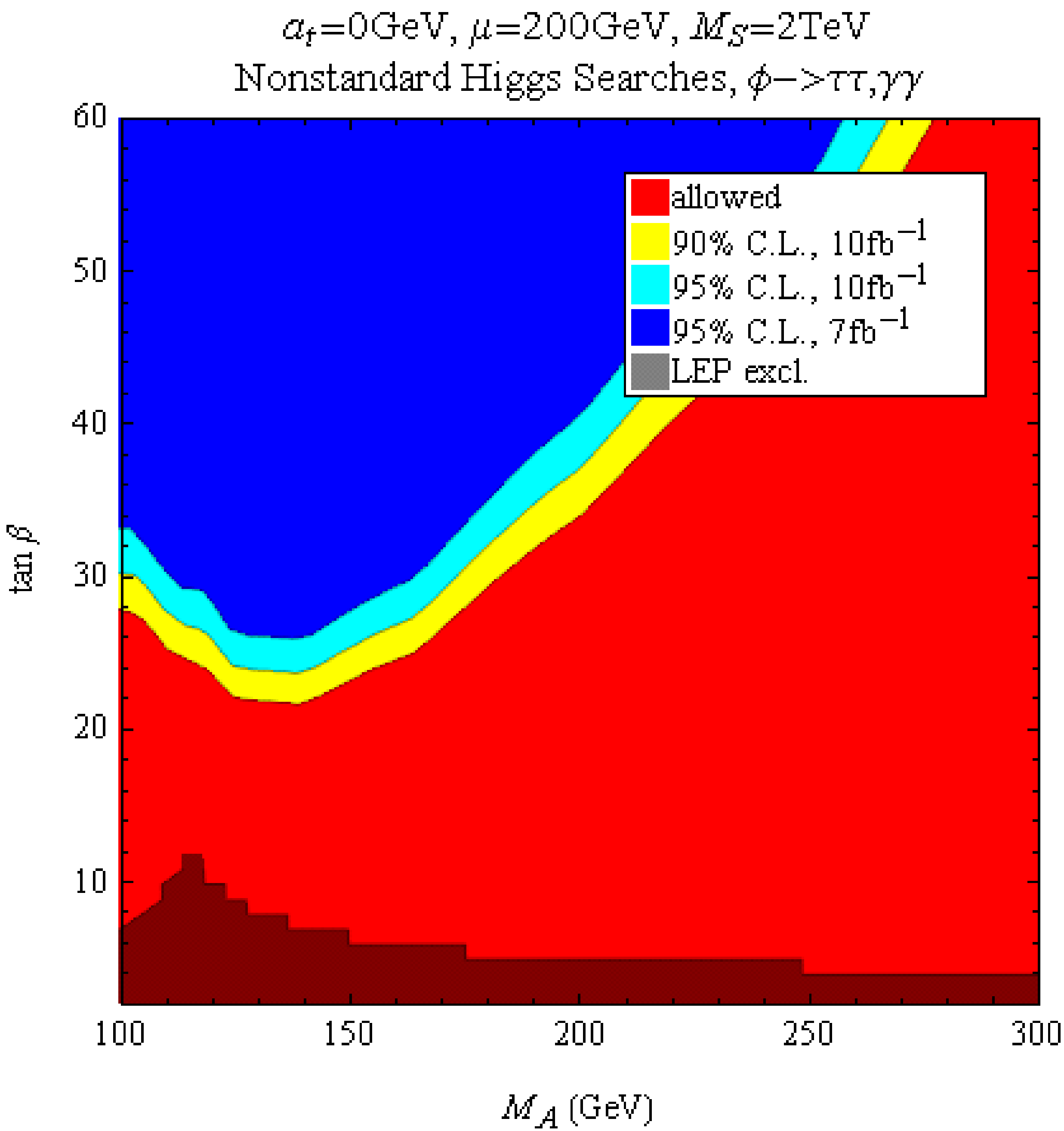
$$M_S = 2 \text{ TeV}$$
$$\mu = 200 \text{ GeV}$$
$$a_t = 0$$



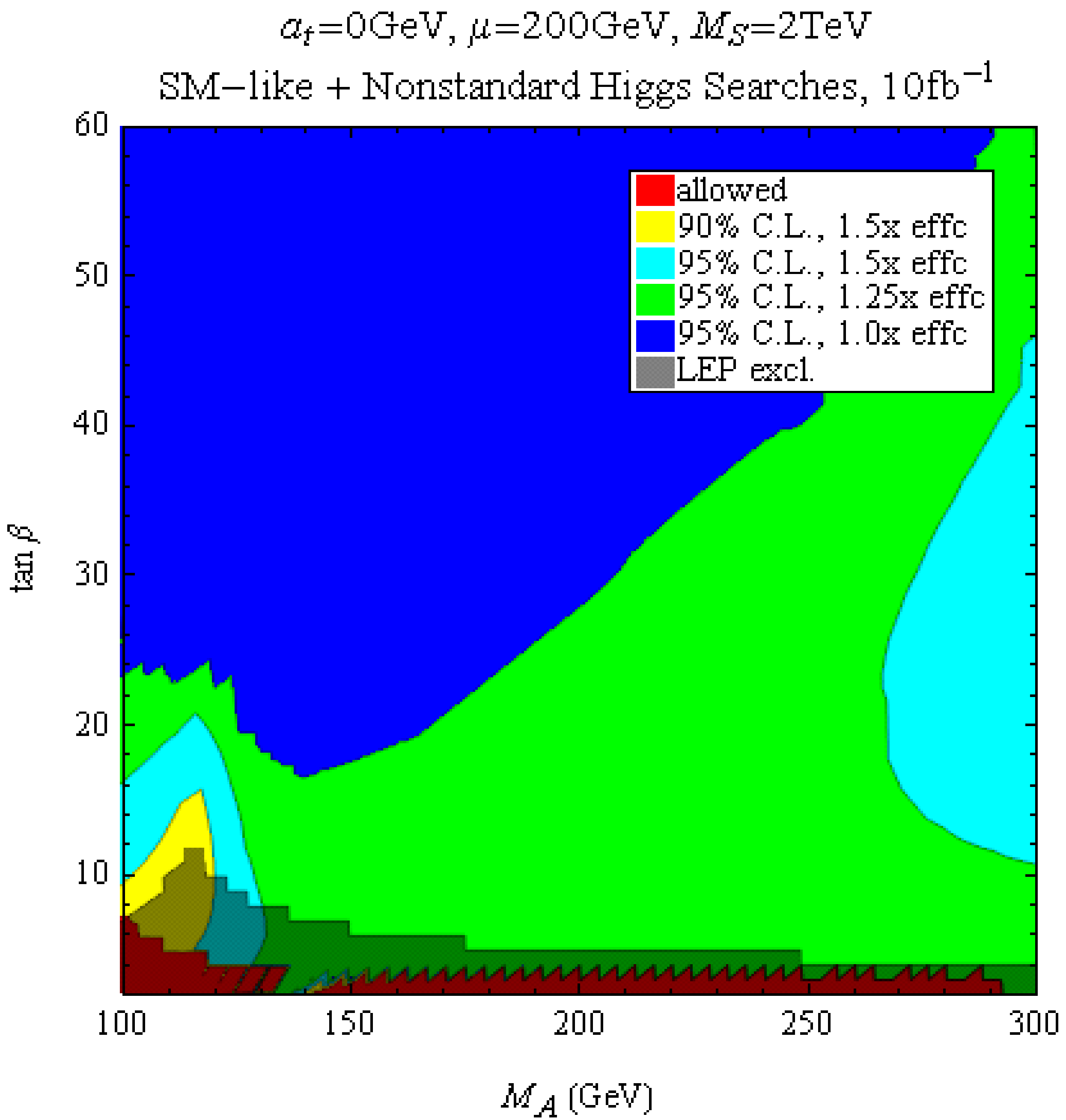
Constraints from SM-like Higgs Searches for Minimal Mixing



Constraints from Nonstandard Higgs Searches for Minimal Mixing



Combined Constraints for Minimal Mixing



Small-α_{eff} Scenario

- Higgs mixing angle → 0 in a region of the $(m_A, \tan\beta)$ plane because of cancellation between tree level and loop corrections to off-diagonal term in the mass matrix:

$$\mathcal{M}_{12}^2 \simeq -(m_A^2 + m_Z^2)/\tan\beta + \frac{h_t^4 v^2}{16\pi^2}\bar{\mu}\bar{A}_t(\bar{A}_t^{\,2} - 6)$$

$$\bar{A}_t \equiv A_t/M_S,\ \bar{\mu} \equiv \mu/M_S$$

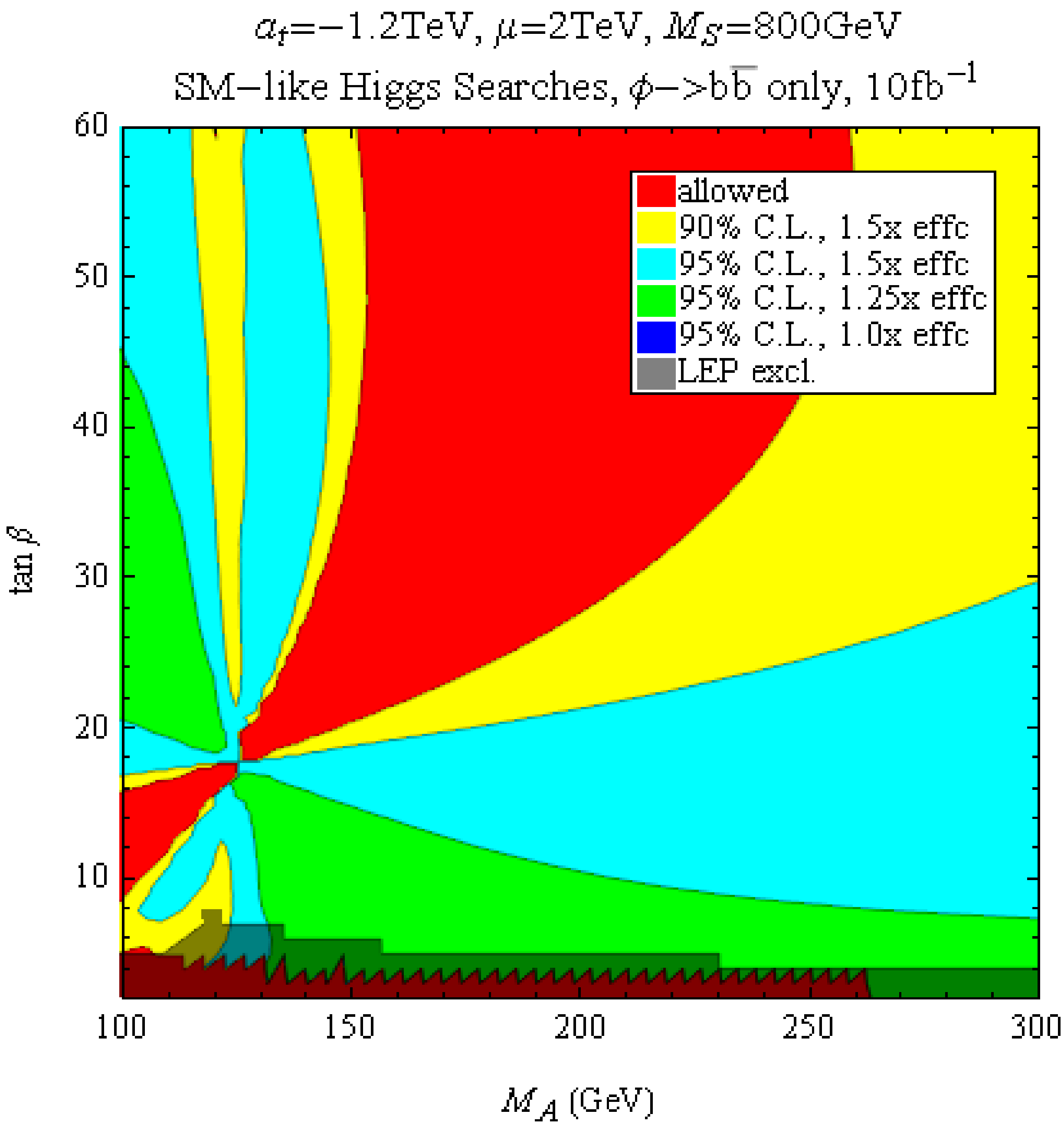
- → need moderate, opposite-signed $A_t,\ \mu$

Small α_{eff} Scenario

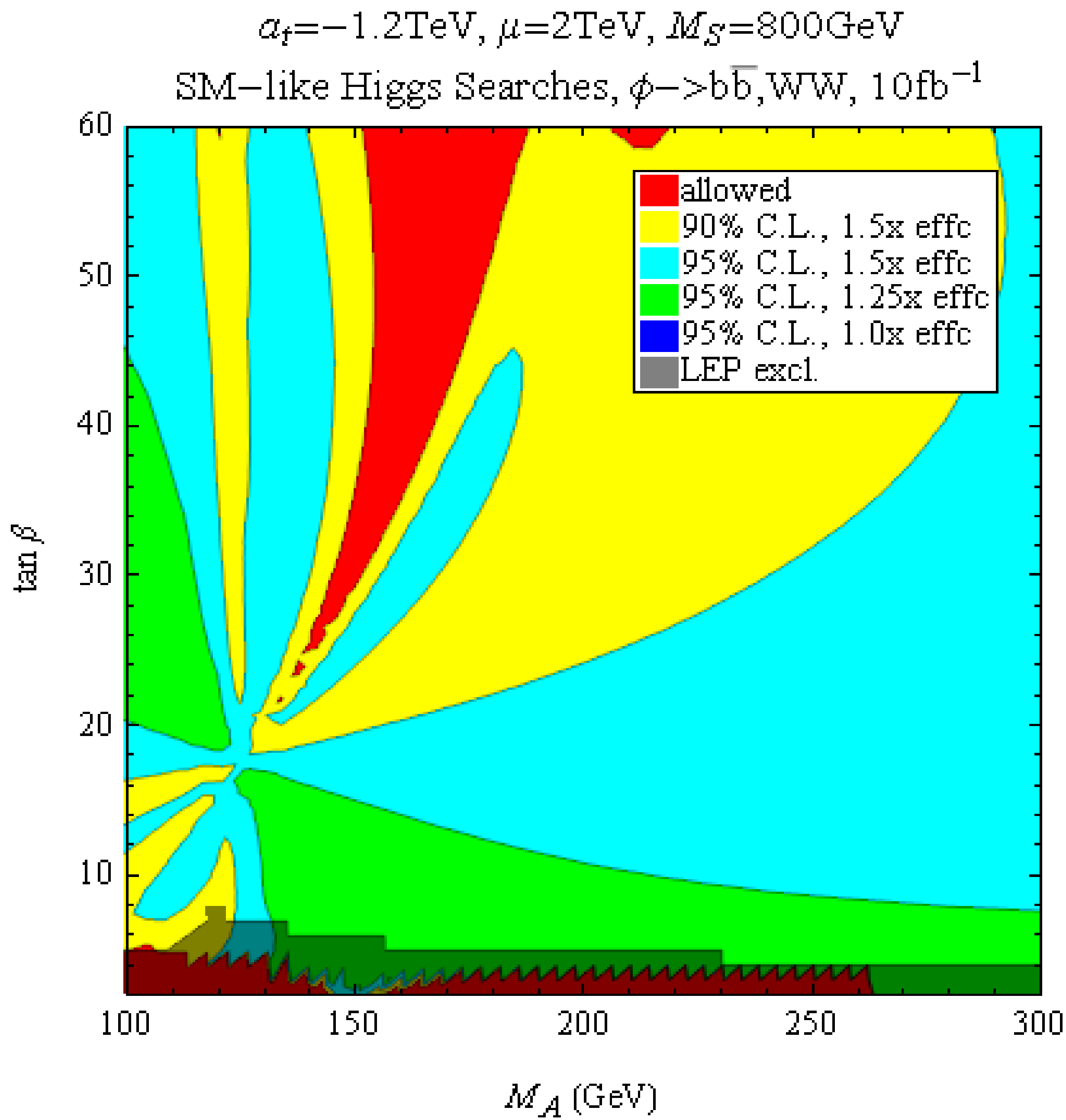
- Strongly suppresses $h \rightarrow b\bar{b}$ search channels, enhances $h \rightarrow WW$
- Demonstrates utility of WW in low-mass region

$$M_s = 800 \text{ GeV}$$
$$\mu = 2 \text{ TeV}$$
$$a_t = -1.2 \text{ TeV}$$

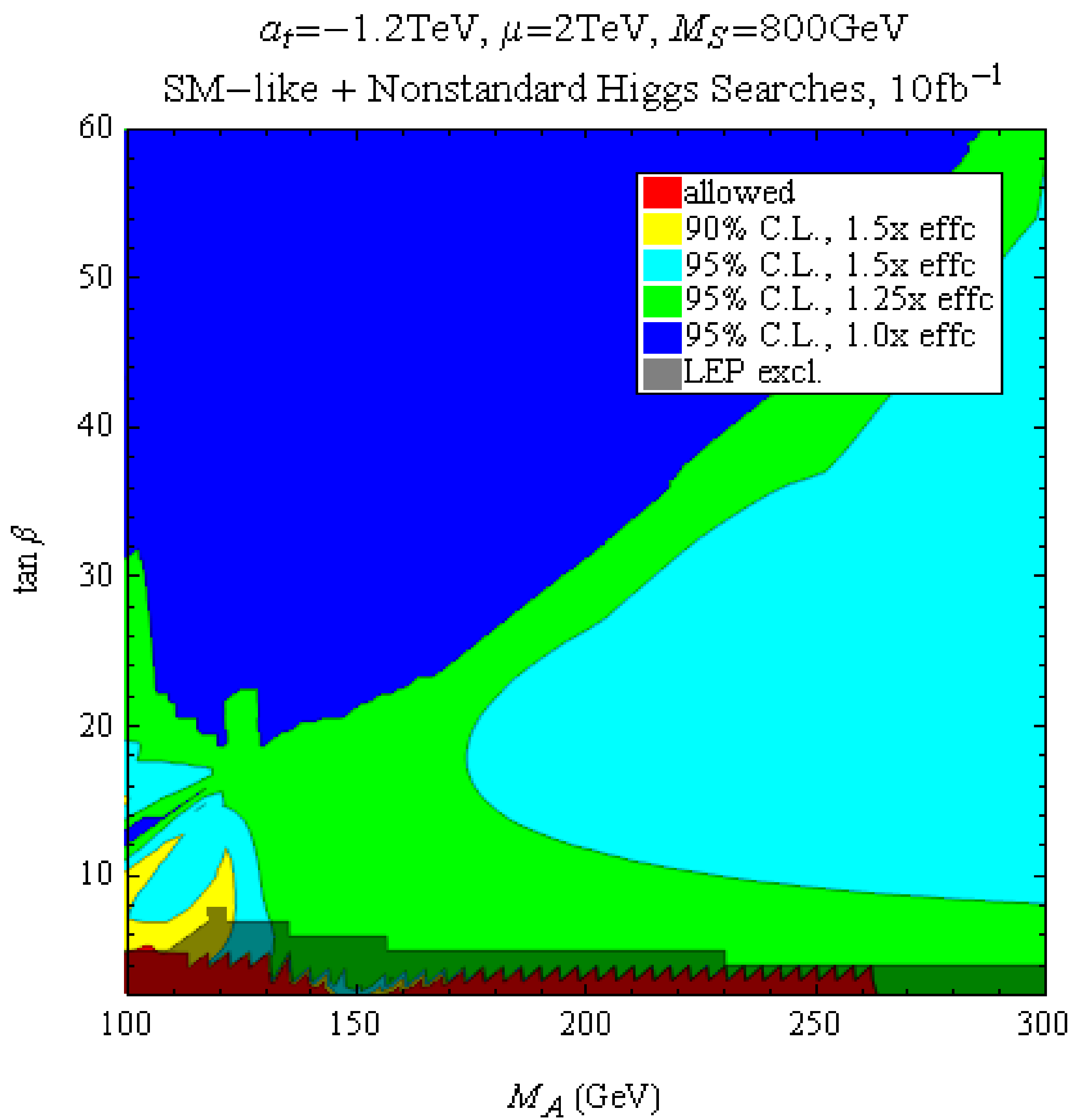
h,H→bb search for SM-like Higgs for small α_{eff}



(h,H→bb) + (h,H→WW) search for SM-like Higgs for small α_{eff}



Combined search for small α_{eff}



Conclusions

- The Tevatron has the potential to probe almost all of MSSM Higgs parameter space at 95% C.L.
- Facilitated by complementarity between SM-like and nonstandard Higgs search channels
- 10 fb^{-1} and 25% improvement in efficiency is necessary in all benchmark scenarios, even with a Higgs just over the LEP bound as in minimal mixing
- Decoupling limit requires 50% efficiency improvement in the maximal mixing and small α_{eff} scenarios
- Complementarity between bb and WW channels in SM-like Higgs searches can extend coverage when h is fermiophobic in the down sector, even in the low-mass region
- 3σ evidence is not expected in any scenario